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The Ionization Structure of Planetary Nebulae

V. NGC 3242

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Received_______________

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ABSTRACT

Spectrophotometric observations of emission line intensities over the spectral range 1400 Å to 9600 Å have been made in five positions in the planetary nebula NGC 3242. In two of the positions, both the weakness of the λ1548,1550 C IV resonance lines and the steepness of the Balmer decrement suggest the possibility of internal dust in the nebula; this possibility should be further investigated. The electron temperature measured from the [O III] lines varies little from the average value of 11,100 K, which is in reasonably good agreement with the less accurate value of 12,900 K measured from the Balmer continuum. As in the previous studies in this series, the λ4267 C II line implies a C^{2+} abundance that is much higher than that determined from the λ1906,1908 C III] lines. This discrepancy decreases with increasing distance from the central star, again suggesting that the excitation mechanism for the λ4267 line is not understood. Standard equations used to correct for the existence of elements in other than the optically-observable ionization stages give results that are consistent and in agreement with abundances calculated using ultraviolet lines and with those found by Aller and Czyzak. The logarithmic abundances (relative to H=12.00) are: He=10.96, O=8.64, N=7.96, Ne=8.04, C=8.41, Ar=6.15, and S=6.51. The He, and, to some degree, O, N, Ne, and C, abundances are somewhat lower than those measured in NGC 6720 and NGC 6853, suggesting that less (perhaps no) mixing of processed material occurred in the progenitor to NGC 3242. The S, and, to some extent Ar, abundances also appear to be somewhat low, perhaps implying that the progenitor to NGC 3242 formed out of metal-poor material.

I. INTRODUCTION

The four previous papers in this series (Barker 1980; Barker 1982; Barker 1983; and Barker 1984; hereafer, Papers I, II, III, and IV, respectively) analyzed optical and ultraviolet observations of different positions in the planetary nebulae NGC 6720, NGC 7009, and NGC 6853. The idea behind these studies is to measure optical and UV emission line intensities in the same nebular positions using similar entrance apertures. Since the ionization frequently changes drastically with position in an extended nebula, this procedure is almost essential in order to make a meaningful comparison between UV and optical measurements. The ultimate goals are (1) to observe elements in more stages of ionization than is possible from optical spectra alone; this provides a check on optical ionization correction procedures, which are still useful for nebulae that are too faint to observe with the International Ultraviolet Explorer (IUE) satellite, (2) by averaging measurements made in different parts of the nebula, to get particularly accurate total abundances so that small differences between nebulae will become apparent; such differences can be sensitive tests of theoretical predictions regarding CNO processing and mixing in the progenitors of planetaries, and (3) to further investigate the discrepancies found in Papers II, III, and IV between optical and UV measurements of the abundance of C; these discrepancies need to be understood before we can have confidence in optical measurements of that important element.

I chose NGC 3242 as the next planetary in this series primarily because it has a high surface brightness and so can be observed with reasonable exposure times using the smaller of the two IUE entrance apertures. In addition, it has measurable He II UV and optical emission in even the outermost positions, facilitating the difficult task of combining the UV and optical observations.

Finally, Aller and Czyzak (1983, hereafter AC) found a rather large discrepancy between the optical and UV measurements of the C^{2+} abundance; I felt that it would be interesting to see if this discrepancy is correlated with position in the nebula, as I found in Papers II, III, and IV.

II. Observations

Spectra of five positions in NGC 3242 were obtained on a total of 13 different nights between 1982 January and 1984 April using the IUE satellite and three different optical instruments at Kitt Peak National Observatory. Nearly all the important emission lines in the spectral range 1400-9600 Å were measured one or more times.

a) Optical Observations

Preliminary observations were made with the Intensified Reticon Scanner (IRS) at Kitt Peak in 1982 January using the No. 1 90 cm telescope. The primary goal was to select positions with a wide range of ionization, but these measurements also provided useful checks on subsequent ones. The bulk of the optical observations were made in 1983 December and 1984 March, using the 2.1 m telescope and the intensified image dissector scanner (IIDS). Spectra were obtained through a 3.4" diameter aperture using two grating settings covering the range 3400-5100 Å and 4600-7200 Å with resolutions of about 10 Å (FWHM). The blue spectral region was observed on three different nights and the red on two. Finally, intensities of the near-infrared λ9069 and λ9532 [S III] lines relative to several stronger visual lines were measured on two nights in 1982 January using the Harvard sequential scanner (see Paper I) and a 4.4" diameter entrance aperture.

b) Correction for Interstellar Reddening

The amount of interstellar reddening can be estimated by comparing the observed and theoretical intensities of the H lines (the "Balmer decrements"). Positions 3-5 have decrements consistent with a reddening parameter, c, of 0.15, in reasonably good agreement with values found by other observers (see the summary by Koppen, 1983). Position 1, and, to a smaller degree, position 2, have somewhat steeper decrements that are more consistent with c=0.35 and c=0.25, respectively. Condal et al. (1981) also found evidence for larger H_α/H_β ratios at approximately these positions and attributed the effect to dust within the nebula. The weakness of the C IV lines in these positions also suggests that there may be dust in the nebula (see § IVe). It would clearly be worthwhile to explore this possibility further, perhaps by using high dispersion spectrophotometry to compare the intensities of the Balmer lines at the near (blue shifted) and far (red shifted) sides of the nebula. This method has been tried for some planetaries (Osterbrock 1974, Doughty and Kaler 1982) but not NGC 3242. Note, however, that infrared measurements by Moseley (1980) as analyzed by Natta and Panagia (1981) indicate that NGC 3242 has an unusually low amount of internal dust. In view of this and the rather small differences in the Balmer line intensities, I do not feel that the evidence for a steeper decrement for positions 1 and 2 is conclusive. In addition, a larger value of c than 0.15 would give even poorer agreement between the predicted and observed λ1640 He II fluxes in position 1 (see § IIc). I therefore adopted a value of c = 0.15 for all five positions. A larger value for positions 1 and 2 would have very little effect on the conclusions of this paper.

The intensities listed in Table 2 have all been calculated by multiplying the observed intensities by $10^{0.15f(\lambda)}$; the values of $f(\lambda)$ are also listed in Table 2. Note that there is generally very good agreement between the observed and theoretical (Brocklehurst 1971) intensities of $H\alpha$, $H\beta$, $H\gamma$, $H\delta$, H9, and H10

(285, 100, 46.9, 25.9, 7.3, and 5.3, respectively). The intensities of the [O II] lines at λ3727 listed in Table 2 have been corrected for blending with other lines as described in Paper III. This correction resulted in the observed intensities being multiplied by factors of 0.38, 0.49, 0.62, 0.86, and 0.58, for positions 1-5, respectively.

c) Ultraviolet Observations

The ultraviolet observations were made with the small (~3.2" diameter) entrance aperture of the IUE satellite in 1982 July. Table 1 lists the offsets with respect to the central star, the IUE exposure numbers, and the exposure times. The offsets were made under the assumption that the center of light position measured by the IUE fine error sensor coincided with the central star. As a check, exposures were taken with the small aperture centered on the assumed position of the central star. The observed stellar continuum was about as strong as in exposures obtained by other observers through the large IUE entrance aperture, and it therefore seems probable that the IUE observations were made within 1"-2" of the indicated positions. The data were reduced in 1983 January at the IUE Regional Data Analysis Facility at Goddard Space Flight Center using the 1980 May calibration (the same calibration used in Papers II, III, and IV).

No emission lines could be observed by both the IUE and optical telescopes, but several methods can be used to put all the observations on the same intensity scale. One method is to directly compare absolute flux measurements, after correcting for the (small) difference in the areas of the entrance apertures. A check on this method is that, for the physical conditions of NGC 3242 (see §III), I(λ1640) should then equal 6.6 I(λ4686) (Seaton 1978). The predicted and observed <u>fluxes</u> (uncorrected for interstellar extinction) are compared in Table 1. The agreement is only fair for position 1, and, as discussed above, it would have been even worse if a larger value of c had been assumed. Positions 2, 3, and 4 agree extremely - perhaps fortuitously - well in view of the uncertainties inherent in this method. I attribute the disagreement at position 5 to the fact that He II emission varies drastically near the outer parts of the nebula. (I(λ4686) is 6 times greater at position 4 than position 5, for example, even though the two positions are at the same angular distance from the central star.) Indeed, SWP 18740, taken in 1982 December, gave F(λ1640) nearly 10 times greater than SWP 17424. (SWP 18740 was supposed to be on position 5, but there was some difficulty in pointing the satellite during this exposure, and it may have been in error by 3-4".) In the end, for positions 1, 2, and 3, the UV intensities were put on the same scale as the optical ones by requiring that I(λ1640)=6.6 I(λ4686). For positions 4 and 5, where the He II emission is much more variable, the normalization was done by comparing absolute fluxes. The validity of the latter method is supported by the fact that, despite the discrepancy in the He II λ1640 fluxes between SWP 17424 and SWP 18740, their λ1906,1909 C III] fluxes differed by only 20%. Finally, the SWP and LWR intensities were combined by assuming that the small LWR aperture has an effective area of 0.83 times the SWP's (Harrington, Seaton, Adams, and Lutz 1982); this is close to the value of 0.79±0.05 that I measured by comparing λ1906,1909 emission line intensities on the SWP and LWR spectra.

One check on the normalizing procedure is the ratio of the UV and optical O III lines, I(3133)/I(3444), which should be 2.51. The observed ratios are 4.07, 2.26, 2.22, and 12.8 for positions 1, 2, 3, and 5, respectively. I again attribute the discrepancy for position 5 to the sensitive dependence of He II emission on position in the outer parts of the nebula; this will have a drastic effect on the O III lines, since they result from the Bowen fluorescent mechanism. Another check is the O^{2+} abundance measured from the λ1661,1666 O III] line, compared to that from the λ5007 line (Table 4). The agreement is only fair, but this is not surprising in view of the faintness of the UV lines. In summary, I feel that the UV/optical ratio of line intensities is good to ~20% for positions 2, 3, and 4, and to ~50% for positions 1 and 5.

d) Observational Errors

Aside from possible systematic errors discussed above, the ultraviolet intensities are judged to be accurate to within a factor of 2 for the faintest lines (less than 20% of H_β), to ~40% for those of intermediate intensity (between 20% and 80% of H_β), and to ~20% for the strongest lines. While these errors may seem high, errors in electron temperatures generally have a greater effect on the accuracy of the abundances (discussed in § III) than do those in line intensities.

Based on a comparison between the IRS and IIDS results, and between IIDS measurements made on different nights, the intensities of the strongest optical lines are judged to be accurate to ~10%, those weaker than half of H_β to be accurate to ~20%, and even the faintest lines to be accurate to ~30%. The λ3727 line intensity is good to only a factor of 2 for positions 1, 2, 3, and 5 because of the large corrections for blending these (see § IIc). The intensity of the λ9532 line and, to a lesser degree, of the λ9069 line, were affected by terrestrial H_2O absorption as discussed in Paper III and are good to only ~50%. Finally, intensities in Table 2 labeled with colons are uncertain by approximately a factor of 2.

An additional source of error in the optical observations results from the large zenith distance of NGC 3242 at the latitude of Kitt Peak. Although it was observed only within an hour of the local meridian, the air mass was as high as

1.6. Because of atmospheric refraction, somewhat different parts of the nebula were therefore sampled in different regions of the spectrum, an effect which is most serious for positions 4 and 5, where the ionization changes the most drastically.

III. TEMPERATURES, DENSITIES, AND IONIC ABUNDANCES

Calculations of the electron temperature (T_e), electron density (N_e), and ionic abundances in the different positions were made using the same methods and atomic constants as in Paper III. The results for N_e and T_e are summarized in Table 3. The [S II] lines are faint and so the values of N_e measured from them are rather uncertain. The [Ar IV] lines are also faint. In addition, a weak He I line blended with λ4711 will lead to a slight underestimate in N_e (primarily in the lower ionization positions where He I emission is strongest), while other evidence (Czyzak et al., 1980) suggests that errors in the Ar^{3+} constants may lead to overestimates in N_e. Even so, the agreement between the two indicators (in positions 3 and 4) is reasonably good, and the adopted values are similar to those found by others (see Koppen 1983 for a recent summary). Fortunately, only the O^+, and, to a lesser degree, the S^+ abundance calculations are sensitive to the assumed N_e.

Of the three indicators for T_e, the O^{2+} ratio is by far the most accurate, and this value was therefore adopted for all five positions. There is very litle variation in the O^{2+} T_e, consistent with the T_e map by Reay and Worswick (1982), who found "a fairly even distribution at 11000 K." These T_e measurements are also consistent with those found by other observers (Koppen 1983). The S^{2+} determinations are much less certain for reasons described earlier, but at least they indicate that there is no evidence for a significantly lower T_e in regions of lower ionization as is sometimes the case (e.g., Paper IV). The Balmer continuum T_e was measured by extrapolating the shortward and longward continua to the Balmer limit, and dividing the difference $i(\lambda3646^-)-i(\lambda3646^+)$ by $I(H\beta)$. This ratio was converted to T_e by using Equation (1) from Barker (1979). This method is extremely sensitive to errors in c, uncertainties in estimating the continuum, and uncertainties in the instrumental calibration in this wavelength region. The agreement with the O^{2+} T_e's must therefore be considered reasonably good. There is certainly no evidence that T_e's measured from the Balmer continuum are lower than the O^{2+} T_e's, as has been claimed for some planetaries (see Barker 1979 for a discussion). In summary, the electron temperature for NGC 3242 is quite constant across the nebula and has apparently been measured quite accurately.

The ionic abundances using the values of T_e and N_e given at the bottom of Table 3 are listed in Table 4. In NGC 3242, most of the elements are in stages of ionization that are similar to O^{2+}, so the O^{2+} T_e should be appropriate for them.

IV. TOTAL ABUNDANCES

Total abundances may be found by simply adding together all the ionic abundances or by using only optically measured ionic abundances and correcting for the presence of elements in optically unobservable stages of ionization. The former procedure would appear to be the more reliable, but unfortunately relatively small errors in T_e will result in very large errors in abundances determined from UV lines. At the very least, however, this method serves as a valuable check on the second procedure, which is often the only one possible when no UV data are available. Both methods were used whenever possible, and the results are summarized in Table 4. The abundances labeled "optical" have been calculated by multiplying the optically measured ionic abundances by the listed values of i_{cf}, the ionization correction factor; the equations used to calculate i_{cf} values are given in Paper III. The abundances labeled "UV + optical" are simple sums of all the ionic abundances.

Except for He, the errors assigned to the abundances are based on the errors estimated for T_e, N_e, and the line intensities. In most cases, the errors in T_e dominate over other sources.

a) Helium

The three different He I lines agree very well, and the average He^+/H^+ abundance given in Table 4 for each position is a straight sum of the three measurements; the total He abundance is the sum of the He^+ and He^{++} abundances. Since He II emission is present in even the positions of lowest ionization, little if any He is expected to be in the form of He^o. The constancy of the total measured He abundance bears this out.

b) Oxygen

The λ1661,1666 O III] lines are rather faint, so, as mentioned in § IIc, it is not surprising that the agreement between the optical and UV measurements of the O^{2+} abundances is only fair. No λ1403,1409 O IV] emission was detected in the IUE spectra, consistent with the rather small values of i_{cf} determined from the optical lines. The total calculated O abundance agrees fairly well for the different positions, but the range in ionization in NGC 3242 is too small for this agreement to be considered a meaningful confirmation of the validity of the method used to calculate i_{cf} for O.

c) Nitrogen

Almost all (>99.7% for position 1) of the N in NGC 3242 is in the optically-unobservable states of N^{2+} and N^{3+}, so this planetary provides a good check on the validity of the i_{cf} for N. Unfortunately, both the O^+

abundance (which is used to calculate i_{cf}) and the N^+ abundance (which depends on the intensity of the λ6583 line, which is faint and partially blended with H_α), are quite uncertain. I believe that most of the scatter in the optically-measured N abundances is due to these factors. I attribute the large discrepancy for position 4 to telescope guiding errors;as discussed previously, the ionization is very sensitive to position in positions 4 and 5. Excluding position 4 gives the (unweighted) averages N/H (optical) = $(0.91\pm0.11) \times 10^{-4}$ and N/H (UV + optical) = $(1.5\pm0.4) \times 10^{-4}$; considering the huge i_{cf}'s, I feel that this agreement is a rather strong confirmation of the validity of the optical technique.

d) Neon

The weakness of I(3426) relative to I(3444) indicates that most or all of I(3426) is due to λ3429 O III rather than λ3426 [Ne V]; the Ne^{4+} abundance is therefore negligible. Note that the total Ne abundance inferred from the Ne^{2+} abundance is reasonably consistent with that found by summing the Ne^{2+} and Ne^{3+} abundances. In addition, the total measured Ne abundance is constant and not overestimated in the outer positions (as in Papers I and IV); in NGC 3242, as in NGC 7009, the ionization is so high that there is little O^+ and so the different efficiencies of the O and Ne charge transfer reactions are not important (see Paper I and references therein).

e) Carbon

As in NGC 6720, NGC 7009, and NGC 6853 the C^{3+} abundance in the inner positions inferred from the λ4267 line is much larger than that found using the UV λ1906,1909 lines. The ratio of the two measurements is 5.3, 2.5, 3.4, 2.2, and 1.2 for positions 1-5, so the discrepancy is worst nearest the central star, as was the case with the other planetaries. I know of no observational error that could cause this discrepancy. In particular, although combining the UV and optical observations can lead to systematic errors (see § IIc), using the O III rather than He II lines to do this would given an even <u>worse</u> discrepancy (8.5) for position 1. The λ4267 line intensity is weak, but the mean error in it (based on three nights of observing) is smaller than 20% for each position. In addition, AC, using different observational material, also found a large discrepancy (a factor of 8). Finally, although a large (~3000 K) overestimate in T_e could also explain the discrepancy, such an error is highly improbable in view of the apparent accuracy of the T_e measurements discussed in § III. These and other possibilities were discussed in Paper II; there still seems to be no satisfactory explanation for this phenomenon.

Another interesting result for C is the behavior of the λ1548,1550 CIV resonance lines. These lines are generally weaker in planetaries than model calculations predict, and NGC 3242 seems to be an extreme case. Koppen (1983; "model A") predicts that these lines should be about twice as strong as the λ1906,1909 C III] lines when averaged across all of NGC 3242, but, as shown in Table 2, the observed ratio is never greater than 0.23. This discrepancy is particularly pronounced in position 1, where no C IV emission is observed, despite the fact that this is the position of highest ionization, where one would expect the highest C IV/C III] ratio. A similar, but much less pronounced effect was found in NGC 6720 (Paper II) and was attributed to preferential absorption of the C IV resonance lines by internal dust in the nebula. Koppen and Wehrse (1983) claim that the effect is generally too great in planetaries to be explained by reasonable quantities of dust, and they and Koppen (1983) show that the presence of a large central cavity could explain it more satisfactorily. This idea is somewhat supported by the fact that the effect is present in NGC

6720 (the Ring Nebula), which does have a central cavity, and NGC 3242, which has a double shell structure, but not in NGC 6853 (the Dumbell Nebula; Paper IV), which has a very different geometry. On the other hand, as discussed in § IIb, the Balmer decrements in NGC 3242 suggest that there may indeed be some internal dust in positions 1 and 2. It would clearly be worthwhile to search for this dust observationally, as suggested in § IIb. It would also be interesting to see if the central cavity model of Koppen (1983) can reproduce the positional variation of the C III] and C IV lines given in Table 1.

f)Argon

There is no measurable λ7005 [Ar V] emission, so presumably most of the Ar is in the form Ar^{2+} and Ar^{3+}. Note that the calculated total Ar abundance is very constant across the nebula. The equation $Ar/H=1.5\ Ar^{2+}/H^{+}$ (see Paper I), which is a useful approximation for faint planetaries where only the λ7135 [Ar III] line is observable, gives an average Ar/H ratio of 0.65×10^{-6}, about half the measured value of 1.4×10^{-6} (see Table 5).

g) Sulfur

The total calculated S abundance is fairly consistent at the different positions, but, since most of the S is predicted to be in the form of S^{3+}, it would clearly be very valuable to have infrared observations of the 10.5μm [S IV] line at these positions.

V. DISCUSSION

The total abundances in the first row of Table 5 are unweighted averages of measurements made in the different positions. Except for C, only optical measurements were used because they are less sensitive to errors in T_e and because of the uncertainties inherent in combining the UV intensities with the optical ones. For the reasons discussed in § IV, only positions 1, 2, 3, and 5 were used for N. Note that the errors listed in Table 5 come from comparisons between the different positions and do not allow for systematic errors such as those introduced by uncertainties in the atomic constants.

It is interesting to compare the abundances with those found by AC, who used different UV and optical data and a different analysis that involved the use of theoretical models. Considering these differences, the agreement is remarkably good.

In general, the abundances in all the objects in Table 5 are quite similar, but there are some interesting differences. First, the S abundance in NGC 3242 (and NGC 6853) appears substantially lower than in the others. Although the S abundance measured in both planetaries is somewhat uncertain (see Paper IV and § IVg), Beck et al. (1981) measured the S^{3+} abundance directly and found a similar total S abundance (4.9×10^{-6}) in NGC 3242. This S abundance is about 60% lower than the average for the 18 planetaries they observed, similar to the S deficiency implied by Table 5. A similar statement can be made for Ar; Beck et al. measured an abundance of 1.6×10^{-6}, in good agreement with the value given in Table 5 and about 35% lower than the average for their other planetaries. There is fairly good evidence, then, that NGC 3242 is somewhat underabundant in S and Ar relative to other planetaries, H II regions, and the Sun. Since some arguments (see Barker and Cudworth, 1984, and references therein) suggest that S and Ar may be better indicators of heavy element abundances than are lighter elements, it is possible that the progenitor to NGC 3242 may have formed out of material that is more metal poor than did the other objects listed in Table 5.

A second feature of Table 5 is the low He abundance in NGC 3242. I believe that the abundance really is this low because the agreement with the measurement by AC is so good and because the internal agreement (see Table 4) is also excellent. It therefore appears likely that NGC 3242 has experienced significantly less (perhaps no) enhancement of He-rich material compared to the other planetaries in Table 5. This idea is supported by the fact that the N, Ne, and, to some extent, O and C, abundances are also low, especially compared to NGC 6853 and NGC 6720, where some mixing of processed material has clearly occurred (see Papers I and IV).

VI. CONCLUSIONS

In summary, NGC 6853 is another planetary nebula for which total abundances can apparently be estimated from optical data alone. The one element for which this is not true is C; the λ4267 line again gives a higher abundance than the UV lines. This discrepancy is greatest nearest the central star, implying that the λ4267 line may be excited by processes other than pure recombination. The good internal agreement of the abundance measurements and the excellent agreement with the measurements by AC indicate that the abundances in NGC 3242 are known to quite high accuracy. The low S and Ar abundances suggest that the progenitor to NGC 3242 may have formed in somewhat metal-poor material. The low abundances of the lighter elements, especially He, suggest that there was little or no mixing of processed material into the outer layers of the star before it became a planetary nebula. Finally, there is intriguing circumstantial evidence for the presence of dust in NGC 3242. It would clearly be worthwhile to make a direct observational test for dust using a technique such as that described in § IIb.

I am grateful to the IUE and Kitt Peak staffs for their assistance in obtaining the measurements. Some of the Kitt Peak 2.1m observations were made via a remote TV, voice, and computer link that was a delight to use, and I am especially grateful to the developers of this system.

TABLE 1

PARAMETERS OF OBSERVED POSITIONS

PARAMETER	POSITION 1	2	3	4	5
Offset (arcsec)	4E,3N	3W,4N	6W,8N	9W,12N	12E,9N
SWP number	17423	17428	17429	17422	17424
Exposure (min)	15	15	20	50	72
LWR number	13680	13683	13684	13679	14791
Exposure (min)	40	30	30	70	70
F(Hβ)[a], 3".4 ent.	1.56	2.05	2.25	0.88	0.61
F(λ1640)[a] predicted	2.80	2.46	2.21	0.39	0.05
F(λ1640)[a] observed	4.68	2.42	2.54	0.41	0.02

[a] Units of 10^{-12} ergs $cm^{-2} sec^{-1}$.

TABLE 2

LINE INTENSITIES

			I (λ)				
λ(Å)	ID	f (λ)	Pos. 1	Pos. 2	Pos. 3	Pos. 4	Pos. 5
1487	N IV]	1.23	31.2	...	14.8	20.9	...
1548,1550	C IV	1.18	...	17.2	48.8	16.2	...
1640	He II	1.14	305.	202.	162.	69.4	4.4
1661,1666	O III]	1.13	...	42.2:	32.5:	...	6.6:
1747	N III]	1.12	10.3	13.0	6.9	6.9	9.4
1906,1909	C III]	1.23	158.	216.	214.	244.	152.
2326,2328	C II]	1.35	...	...	...	13.0	12.3
2422	[Ne IV]	1.12	26.8	14.3	...	...	...
3133	O III	0.45	94.8	38.9	35.0	...	44.7
3204	He II	0.42	35.6	26.1	...	...	...
3426	[Ne V],O III	0.38	5.0	3.2	2.6	...	1.4
3444	O III	0.37	23.3	17.2	15.8	7.8	3.5
3727	[O II]	0.29	2.8[a]	4.4[a]	7.9[a]	28.7[a]	6.3[a]
3798	H 10	0.27	3.8	4.6	5.0	5.9	4.5
3835	H 9	0.26	6.2	6.6	7.0	8.2	6.6
3869	[Ne III]	0.25	96.9	101.	112.	140.	105.
4069-4076	(blend)	0.21	1.5	1.04	1.2	2.5	0.8
4102	H δ	0.20	26.2	25.8	27.5	31.0	26.5
4267	C II	0.17	0.70	0.58	0.72	0.52	0.28
4340	H γ	0.15	44.2	45.2	47.2	50.3	47.1
4363	[O III]	0.15	12.5	12.1	12.7	14.1	11.7
4471	He I	0.11	2.7	3.2	3.4	4.6	4.4
4686	He II	0.05	45.2	30.3	24.6	10.7	1.9

TABLE 2 continued

4711	[Ar IV]	0.04	5.1	4.1	3.5	4.1	4.2
4740	[Ar IV]	0.03	4.6	3.5	2.8	3.1	3.4
4861	Hβ	0.00	100.	100.	100.	100.	100.
4959	[O III]	-0.03	399.	437.	451.	491.	459.
5007	[O III]	-0.04	1230.	1329.	1353.	1517.	1473.
5200	[N I]	-0.08	...	...	...	0.45	...
5412	He II	-0.13	4.0	2.1	1.7	0.39	...
5755	[N II]	-0.20	...	...	...	...	...
5876	He I	-0.22	6.9	9.4	9.4	10.2	11.7
6300	[O I]	-0.29	...	...	...	0.50	...
6312	[S III]	-0.29	0.36	0.36	0.71	0.49	0.38
6360	[O I]	-0.30	...	...	...	0.13	...
6563	Hα	-0.33	307.	298.	278.	286.	287.
6583	[N II]	-0.34	1.5:	3.6:	4.3	6.2	2.8
6678	He I	-0.35	2.0	2.5	2.2	3.0	3.4
6717	[S II]	-0.36	0.1:	0.34	0.38	0.46	0.56
6731	[S II]	-0.36			0.52	0.49	
7065	He I	-0.40	1.8	2.7	3.0	2.4	2.8
7135	[Ar III]	-0.41	5.6	7.2	7.1	6.0	5.8
9069	[S III]	-0.50	6.8[b]	8.6[b]	5.2[b]	2.7[b]	1.0[b]
9532	[S III]	-0.63	9.1[b]	13.2[b]	6.2[b]	5.6[b]	5.3[b]

[a] Corrected for blending; see text.

[b] Affected by terrestrial H_2O absorption; see text.

TABLE 3

ELECTRON TEMPERATURES AND DENSITIES

QUANTITY	ION	RATIO	POSITION 1	2	3	4	5
N_e (cm^{-3})	S^+	I(6731/I(6717)	...	...	2100	950	...
N_e (cm^{-3})	Ar^{3+}	I(4740)/I(4711)	5400	4800	3300	1600	3300
T_e (K)	S^{2+}	I(9069)/I(6312)	9200:	8200:	1400:	20000:	14500:
T_e (K)	O^{2+}	I(5007)/I(4363)	11400	11000	11100	11100	10500
T_e (K)	H^+	I(Bac)/I(Hβ)	11500	16100	13900	10300	12500
N_e (adopted)			5400	4800	2500	1200	3300
Error			±2500	±2000	±800	±400	±1500
T_e (adopted)			11400	11000	11100	11100	10500
Error			±500	±500	±500	±500	±500

TABLE 4

IONIC AND TOTAL ABUNDANCES

λ(Å)	ABUNDANCE	POSITION 1	2	3	4	5
4471	He^{+}/H^{+}	0.056	0.066	0.070	0.095	0.089
5876	He^{+}/H^{+}	0.053	0.071	0.071	0.077	0.088
6678	He^{+}/H^{+}	0.049	0.064	0.061	0.078	0.088
Average	He^{+}/H^{+}	0.053±0.002	0.069±0.002	0.069±0.003	0.081±0.005	0.088±0.001
4686	He^{2+}/H^{+}	0.039	0.026	0.021	0.009	0.002
	He/H	0.092±0.003	0.095±0.003	0.090±0.004	0.090±0.005	0.090±0.002
3726,3729	$10^4 \times O^{+}/H^{+}$	0.012	0.021	0.028	0.17	0.031
5007	$10^4 \times O^{2+}/H^{+}$	2.7	3.3	3.2	3.6	4.2
1661,1666	$10^4 \times O^{2+}/H^{+}$	...	8.4:	6.0:	...	2.0:
	i_{cf}	1.74	1.38	1.30	1.11	1.02
Optical	$10^4 \times O/H$	4.7±0.9	4.6±0.9	4.2±0.8	4.2±0.8	4.3±0.8
6583	$10^4 \times N^{+}/H^{+}$	0.0021:	0.0056:	0.0063	0.0090	0.0048
1747	$10^4 \times N^{2+}/H^{+}$	0.53	0.88	0.43	0.43	0.92
1487	$10^4 \times N^{3+}/H^{+}$	2.0	...	1.2	1.7	...
	i_{cf}	392.	219.	150.	24.7	139.
Optical	$10^4 \times N/H$	0.82±0.7	1.2±0.9	0.95±0.6	0.22±0.2	0.67±0.4
UV + Optical	$10^4 \times N/H$	2.5±1.2	0.89±0.4	1.6±0.7	2.1±1.0	0.92±0.4

TABLE 4 Cont.

3869	$10^4 \times Ne^{2+}/H^+$	0.63	0.74	0.79	0.99	0.92
2422	$10^4 \times Ne^{3+}/H^+$	0.63	0.42	...	...	...
	i_{cf}	1.74	1.39	1.31	1.17	1.02
Optical	$10^4 \times Ne/H$	1.1±0.2	1.0±0.2	1.0±0.2	1.2±0.2	1.0±0.2
2326,2328	$10^4 \times C^+/H^+$	...	...	...	0.10	0.14
1906,1909	$10^4 \times C^{2+}/H^+$	1.5	2.6	2.4	2.7	2.5
4267	$10^4 \times C^{2+}/H^+$	7.9	6.5	8.1	5.8	3.1
1548,1550	$10^4 \times C^{3+}/H$	...	0.19	0.50	0.17	...
UV	$10^4 \times C/H$	1.5±0.7	2.8±1.2	2.9±1.3	2.9±1.3	2.7±1.2
7135	$10^6 \times Ar^{2+}/H^+$	0.35	0.49	0.47	0.40	0.44
4711,4740	$10^6 \times Ar^{3+}/H^+$	1.1	0.95	0.77	0.86	1.1
	i_{cf}	1.00	1.01	1.01	1.02	1.02
Optical	$10^6 \times Ar/H$	1.5±0.6	1.5±0.6	1.3±0.5	1.3±0.5	1.6±0.6
6717	$10^6 \times S^+/H^+$	0.0025	0.0091	0.018	0.018	0.014
6312	$10^6 \times S^{2+}/H^+$	0.59	0.68	1.3	0.92	0.87
	i_{cf}	5.07	4.18	3.69	2.05	3.59
Optical	$10^6 \times S/H$	3.0±1.8	2.9±1.8	4.9±2.9	1.9±1.1	3.2±1.8

TABLE 5

COMPARISON OF ABUNDANCES

Object	He/H	10^4XO/H	10^4XN/H	10^4XNe/H	10^4XC/H	10^6XAr/H	10^6XS/H	Reference
NGC 3242	0.091±0.001	4.4±0.1	0.91±0.11	1.1±0.1	2.6±0.3	1.4±0.1	3.2±0.5	1
NGC 3242	0.089	4.6	0.81	0.71	2.7	1.8	4.9	2
NGC 6853	0.110	8.4	3.0	2.7	7.6	3.3	5.9	3
NGC 6720	0.110	6.2	2.2	1.6	3.9	3.7	10.	4,5
NGC 7009	0.117	4.8	1.3	1.5	1.5	2.3	13.	6
H II regions	0.117	4.0	0.4	1.3	---	---	18.	7
Sun	0.100	7.4	0.9	1.1	4.5	3.7	17.	2,8

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